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Abstract

The EU Water Framework Directive (WFD) calls for cost-effective measures to achieve a "good status" in all European ground, surface and coastal waters. Besides eutrophication, the degradation of hydro-morphology is the main reason for failing the WFD's objectives in Germany. In this paper, we conceptualize the interactive decision support process BAS*IN*FORM-M for finding proper locations for river restoration. The method combines the recently proposed "stepping stone concept" from aquatic ecology with elements from cost-effectiveness analysis, multi-criteria analysis and participatory approaches. BAS*IN*FORM-M exemplifies a shift away from the isolated restoration of single river reaches towards a consideration of functional relationships within the whole river network. In doing so, it satisfies the WFD's requirement of considering cost-effectiveness without neglecting other important evaluation criteria.

Keywords

Cost-effectiveness analysis, decision support, EU Water Framework Directive, river hydro-morphology, ecological networks, stepping stone concept, BAS*IN*FORM, spatial allocation of restoration actions, participatory decision-making

1 Introduction

Sustainable development calls for a fair balance not only between current and future generations as well as the northern and southern parts of the world, but also between economic activities and the protection of nature (WCED 1987, Klauer 1999). One major approach to such a balance is to establish spatial focal areas for different land uses. That is, some areas are reserved for nature protection, in which human, in particular economic, influence is restricted. In other areas which are provided for economic uses, certain deteriorations of the ecosystems are accepted. The question arises how land can be distributed to the various land-uses in such a way that the economic as well as the ecological demands are properly met.

In landscape ecology, the concept of ecological networks has been developed (Bennett and Mulongoy 2006, Jongman and Pungetti 2004). Its basic idea is to create protection areas which are connected through "corridors" or "stepping stones" (SST).[1] If protection areas, corridors and SST are allocated in a proper pattern, the overall functioning of ecological processes is ensured, while

[1] For example, the European Natura 2000 network of conservation areas is a prominent example of a political implementation of the concept of ecological networks. The text of the habitats directive 92/43/EEC (EEC 1992) explicitly makes reference to stepping stones in Article 10.

room for economic activities can be provided at the same time. Only recently this concept has been transferred by German limnologists and administration to riverine eco systems by DLR (2008) and LANUV (2011) as the so called "stepping stone concept". In this paper, we use the stepping stone concept to conceptualize a methodology for finding proper spatial patterns for river restoration activities in the politically highly relevant context of implementing the EU Water Framework Directive (WFD, Directive 2000/60/EC).

The WFD holds the EU member states responsible for guaranteeing a certain minimum quality standard of waters (Petersen et al. 2009, Petersen and Klauer 2012). Particularly in Article 4.1, the directive demands that, in principle, all groundwater as well as all surface waters should achieve an ambitious environmental objective by 2015, the so-called "good status". For surface waters, the "good status" comprehends a good chemical status and a good ecological status. Good chemical status requires that certain substances do not exceed a threshold concentration. Good ecological status demands that the assemblage of fish, water plants, and invertebrates should only slightly deviate from a certain reference, which is the status of pristine waters of the same type (Article 4 and Annex V WFD). While in German rivers good chemical status is currently already met in 88 % of the water bodies, 91 % of the river water bodies fail to reach good ecological status. This is mainly due to (1) their widespread hydro-morphological degradation including poor passability for the aquatic flora and fauna as well as (2) nutrient pollution (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2010). Both the hydro-morphological degradation and the pollution by nutrients have led to a declining quality of the aquatic ecosystems.

In order to achieve the directive's environmental objectives the member states had to establish a river basin management plan (Article 13 WFD) that includes a programme of measures (Article 11 WFD) for each river basin district by December 2009. An important institutional innovation of the WFD is that member states are obliged to take cost-effectiveness into account when selecting measures for the programme. The competent authorities experienced serious difficulties when trying to follow this requirement. Bathe (2010) has shown for all ten German river basin districts that in general the methodological basis for selecting measures is not well documented.[2] In particular, it remains unclear to date whether at all, and how, cost-effectiveness has been considered by the authorities. Hence, there is an urgent need for conceptual work on how to select cost-effective measures in the context of future water management according to the WFD (Hering et al. 2010).

In the literature, there have not been many examples for a systematic and comprehensive approach to prioritization and spatial allocation of restoration actions (McBride et al. 2010, see Beechie et al. 2008 for a review).[3] However, many individual aspects have been discussed. For instance, Moilanen et al. (2011) and Poole (2002) focus on river continuity and discontinuity. Fausch et al. (2002) indicated the necessity to take life histories of the fish species into account when designing strategies for river restoration. Kocovsky et al. (2009), Kemp and O'Hanley (2010), and O'Hanley (2011) make proposals for how to prioritize the removal of barriers for the passage of migratory and stream resident fish. River morphology, however, has not been extensively addressed in this work. On the other hand, studies on the spatial allocation of hydro-morphological river restoration measures typically only touch upon problems of river continuity (e.g. Timm and Wissmar 2004, Cosair et al. 2009, Chantepie et al. 2011) or concentrate on technical planning aspects (Kofalk et al. 2005, Bartussek 2008, Möltgen et al. 2005). Rohde et al (2006) develop an integrative framework for the pre-selection of river restoration sites, but do not consider the ecological interaction along the river course. Additionally, there is a call for introducing economic methods like cost-benefit analysis, cost-effectiveness analysis or multicriteria analysis as tools for planning, prioritization and

[2] Similar investigations have also been done throughout Europe, e.g. Scheuer & Rouillard (2009), Dworak et al. (2009).

[3] For an overview over DSS in the context of the WFD see Evers, 2005; Todini et al., 2006; Bartussek 2008, Chap. 4). However, these DSS have rarely been applied by the competent authorities.

evaluation of restoration projects (Reichert et al. 2007, Cosair et al. 2009, Holzmueller et al. 2011, Robbins and Daniels 2012).

These deficits are tackled by our approach. Building on BAS*IN*FORM, a methodology for finding cost-effective measures to mitigate nutrient pollution in the setting of the WFD (Klauer et al. 2008, 2012, Rode et al. 2008), in this paper, we develop the concept for an interactive decision support process BAS*IN*FORM-M[4] for finding proper locations for river restoration. It simultaneously addresses river continuity and the hydro-morphology of river sections. BAS*IN*FORM-M combines the stepping stone concept with elements from cost-effectiveness analysis, multi-criteria analysis and participatory approaches in line with the requirements of the WFD.

BAS*IN*FORM-M has been developed in the context of the case of the German Federal State of Brandenburg.[5] Environmental authorities in Brandenburg currently commission state-wide development of so-called "water development concepts" (German: "Gewässerentwicklungskonzepte") in which measures to improve hydro-morphology for all running and still waters are planned, including cost data and information on implementation obstacles. In this context, particularly with respect to data availability, BAS*IN*FORM-M provides a concept for the cost-effective selection and prioritization of these measures.

In the next sections, we describe how the concept of ecological networks has been transferred from terrestrial to aquatic ecosystems using the so-called stepping stone concept. We then explain how the stepping stone approach can be used for finding suitable targeting of river restoration measures and describe the main three steps of BAS*IN*FORM-M in detail. The paper concludes with some reflections on the practical application of BAS*IN*FORM-M and the possibilities to extend its field of application.

2 The ecological stepping stone concept

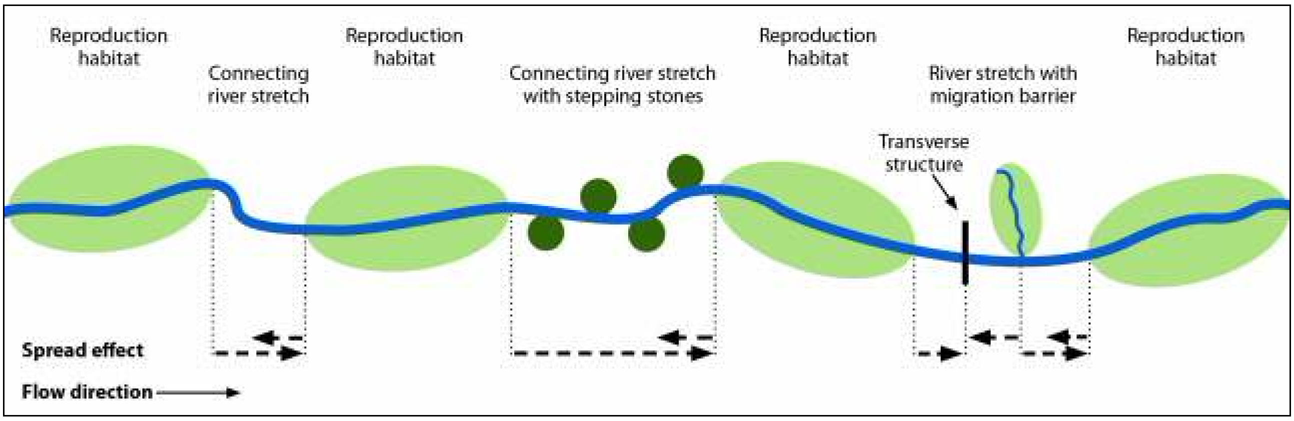
Anthropogenic hydro-morphological modifications have severe impacts on river ecology, e.g. by significantly increasing the flow rate or by interrupting river continuity and therefore inhibiting the migration of aquatic species. To improve river hydro-morphology and to restore longitudinal as well as lateral connectivity, restoration measures have to be undertaken along the watercourse (Lake et al. 2007). However, these measures typically involve physical impacts on the adjacent areas, i.e. the former river floodplains. Thus, in the majority of cases, restoration of rivers is in rivalry with economic activities, such as urban or agricultural land uses.

The so called "stepping stone concept" (DLR 2008, LANUV 2011) is an approach for finding a compromise between river restoration and economic use of floodplains. Its idea was inspired by investigations that indicated a positive effect of natural or semi-natural river stretches on the biology of neighbouring, structurally degraded river reaches (Kail and Hering 2009). Based on this "spread effect", which stems from active and passive migration of the aquatic fauna and flora, good ecological water status can be obtained even though a water body does not offer good habitat conditions on its entire length (DLR 2008: 5). Hence, the basic idea of the stepping stone concept is to improve river ecology by the creation of ecologically effective "reproduction habitats" (DLR 2008), i.e. (semi-)natural or restored river stretches of an adequate size offering good habitat properties, and "stepping stones" (SST), i.e. small, structurally rich river sections that facilitate migration (see Figure 1).

[4] BAS*IN*FORM stands for "river BAS*IN* *IN*FORMation and management system" and -M indicates the focus on river Morphology.

[5] The application of BAS*IN*FORM-M to another German state or EU member state probably needs some adjustments of the concept particularly if river types as well as data availability will differ.

Figure 1: *Sketch of a suitable arrangement of reproduction habitats and stepping stones (SST), based on the stepping stone concept (LANUV, 2011 after DRL, 2008, 11, modified)*



Along the lines of the ecological networks concept, the stepping stone concept provides the basis for a spatially limited, but coordinated implementation of restoration measures. To ensure its functioning reproduction habitats, SST and connecting river stretches have to comply with speci fic conditions:

(1) Physico-chemical water quality

Reproduction habitats and SST can only fulfil their ecological function if physico-chemical quality elements (such as water temperature, oxygen balance, pH, salinity, pollution with organic matter, nutrients and specific substances) do meet certain quality standards. Studies on the benthic invertebrate fauna of different river types have shown a top-down influence of the physico-chemical water quality (Völker 2008). This means that, on the one hand, poor physico-chemical water quality can significantly attenuate or completely offset the positive effect of good hydro-morphological conditions. On the other hand, excellent physico-chemical conditions can facilitate the establishment of diverse biotic communities even in severely degraded hydro-morphological conditions (Völker 2008). Thus, good physico-chemical water quality is a prerequisite for the effectiveness of hydro-morphological restoration measures and hence for the stepping stone concept.

(2) Hydro-morphological quality standards of reproduction habitats and stepping stones

To serve as a reproduction habitat, a river section must meet specific hydro-morphological quality standards. These quality standards significantly depend on the river type (DRL 2008). Based on statistical analysis of monitoring data and expert knowledge, Borchardt and Funke (2007) identify for different river types the hydro-morphological parameters that are of particular ecological importance (e.g. longitudinal banks, transverse banks, flow diversity, depth variance, width variance, substrate type, substrate diversity) and certain features that cause severe ecological deterioration (e.g. backflow) with regard to the type-specific aquatic organisms. For the selected parameters minimum (or maximum) values that have to be reached (or not to be exceeded) must be defined. For example, for rivers in low mountain ranges, Borchardt and Funke (2007) find the set of parameter values given in Table 1.

Table 1: *Hydro-morphological parameters and respective parameter values (Borchardt and Funke 2007, modified)*

Hydro-morphological parameter	Minimum/maximum parameter value in the considered river section (per 100m of length)[6]

River width smaller than 5m	
Longitudinal banks	Number ⩾1
Transverse banks	Number ⩾1
Depth variance	Parameter value ⩾medium (i.e. medium, high, very high)
Substrate type	Sand, gravel, stones, solid rock
Substrate diversity	Parameter value ⩾medium (i.e. medium, high, very high)
River width 5-10m	
Longitudinal banks or transverse banks	Number ⩾1 Number ⩾1
Depth variance or width variance	Parameter value ⩾medium (i.e. medium, high, very high) Parameter value ⩾medium (i.e. medium, high, very high)
Substrate type	Sand, gravel, rubble, stones, solid rocks
Substrate diversity or specialised riverbed structures	Parameter value ⩾medium (i.e. medium, high, very high) Number ⩾2
River width greater than 10m	
Longitudinal banks or specialised run structures	At least rudimental Number ⩾1
Backflow	None
Flow diversity	Parameter value ⩾medium (i.e. medium, high, very high)
Width variance	Parameter value ⩾medium (i.e. medium, high, very high)

Stepping stones (SST) are short sections of a connecting river stretch that meet the hydro-morphological quality standard or may consist of single structural elements such as root plates or depositions of deadwood. In order to fully utilize the spread effect a sufficient number of stepping stones is required in a connecting river stretch (LANUV 2011). Whether or not a river stretch can be considered as enhanced by stepping stones, should be judged by an expert in view of the local conditions and planned restoration measures.

(3) Minimum length and maximum distance of reproduction habitats

The stepping stone concept also formulates restrictions on the spatial distribution of measures to improve river morphology. In particular, reproduction habitats should not fall below a certain minimum length and should not exceed a maximum distance from each other. Hence, for each river type (1) the minimum length of reproduction habitats, and (2) the maximum length of connecting river stretches (i.e. the maximum distance between two reproduction habitats) must be defined (see Table 2). The maximum distance between two reproduction habitats might be extended if the hydro-morphological quality of a connecting river stretch is improved by SST.

***Table 2:** Length and distance parameters (LANUV 2011, modified)*

Water body type	**Length of reproduction habitat (fish and macrozoobenthos)**	**Length of connecting river stretch (with stepping stones) - fish -**	**Length of connecting river stretch (with stepping stones) - macrozoobenthos -**	**Length of connecting river stretch (without stepping stones) - fish -**	**Length of connecting river stretch (without stepping stones) - macrozoobenthos -**

[6] For all hydro-morphological parameters, the possible parameter values are designed in such a way that they cover the whole quality range from worst to best conditions. For example, the values for the parameter "substrate diversity" range from "none" to "low", "medium", high, and "very high". Hence, if classified with the parameter value "none", substrate diversity is totally homogeneous indicating very low or even no morphological dynamics in the considered the river section. On the contrary, if classified as "very high", the river bed is characterised by a strong diversity of substrate types which indicates high morphological activity.

small to mid-sized highland rivers	min. 500 m (continuous)	max. same length as reproduction habitat, max. 3.500 m	max. same length as reproduction habitat, max. 2.500 m	max. quarter the length of reproduction habitat, max. 900 m	max. quarter the length of reproduction habitat, max. 600 m
small to mid-sized lowland rivers		max. same length as reproduction habitat, max. 3.000 m	max. half the length of reproduction habitat, max. 1.000 m	max. quarter the length of reproduction habitat, max. 900 m	max. quarter the length of reproduction habitat, max. 600 m
mid-sized to large highland rivers	min. 1.000 m (continuous) (catchment < 1.000 km^2) min. 2.000 m (continuous) (catchment < 1.000-5.000 km^2)	max. same length as reproduction habitat, max. 4.500 m	max. same length as reproduction habitat, max.3.000 m	max. quarter the length of reproduction habitat, max.1.200 m	max. quarter the length of reproduction habitat, max. 700 m
mid-sized to large lowland rivers	min. 1.000 m (continuous) (catchment < 5.000-10.000 km^2)	max. same length as reproduction habitat, max. 4.500 m	max. half the length of reproduction habitat, max. 2.000 m	max. quarter the length of reproduction habitat, max. 1.200 m	max. quarter the length of reproduction habitat, max. 1.200 m

(4) Passability of connecting river stretches and minimum size of river network

It is a prerequisite for the spread effect and, hence, for the functioning of the stepping stone concept as a whole that river stretches connecting reproduction habitats and SST are passable for fish and other migrating aquatic organisms. Passability of rivers is typically hindered by in-stream structures such as weirs, dams or the like. Migration of species can also be impeded by backflows (especially for organisms that are spread by water drift), clogging of the riverbed, piping, and significant point or non-point pollution or water abstraction. Thus, enabling and sustaining river continuity requires not only purely physical passability (e.g. the absence of transverse structures) but also compliance with some minimal physico-chemical and hydro-morphological quality standards. Finally, depending on the migration habits and needs of relevant fish species, the overall size of the connected river network should not fall below a certain minimum size.

3 BASINFORM-M

BAS*IN*FORM-M exploits the stepping stone concept for guiding decision-makers in selecting those sections along the watercourse where, given the status quo, measures for improvement of river morphology should be implemented, i.e. where reproduction habitats and stepping stones should be located. Besides the requirements of the stepping stone concept, the methodology considers other evaluation criteria such as costs, administrative enforceability – i.e. how easy or difficult is the enforcement of restoration measures in practise – and possible synergies of measures with other political fields (e.g. nature conservation, flood risk management). Because a good physico-chemical water quality is a prerequisite for the effectiveness of hydro-morphological restoration measures, a sufficient water quality is presumed (see above (1)).

The basic idea is to choose river sections which are to be improved to the quality standard of a reproduction habitat or an enhanced connecting river stretch containing SST (see Figure 1). For that purpose, BAS*IN*FORM-M is composed of three working steps (see Table 3 for an overview). For the envisioned practical applications the steps should later be supported and documented by a geo-referenced data bank, i.e. a Geographical Information System (GIS).

Table 3: *Overview of the three working steps of BASINFORM-M*

Step 1: Planning of measures

- Division of planning area into appropriate river sections.
- Planning of possible measures to improve hydro-morphological conditions for each river section along the entire watercourse to (i) meet the hydro-morphological quality standard of a reproduction habitat or to (ii) create an enhanced connecting river stretch containing SST.
- Estimation of expected costs, administrative enforceability, possible synergies, etc. for both options.

Step 2: Setting up successful spatial combinations of measures

- Identification of all spatial combinations of reproduction habitats and connecting river stretches (with and without SST) that fulfil the spatial restrictions of the stepping stone concept by using a GIS-tool.

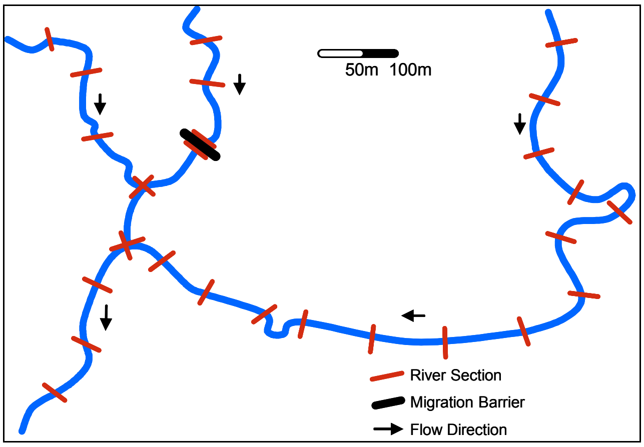
Step 3: Choosing the "best" combination of measures

- Production of a short list of promising combinations by applying several selection algorithms.
- Comparison of combinations supported by a multi-criteria matrix and a GIS map.
- Participative discussion and evaluation of combinations building on local and expert knowledge, addition of new combinations when indicated.
- Final decision.

Step 1: Planning of restoration measures

The river network of the entire planning area is divided into river sections which form the smallest spatial units for the planning of restoration measures (Figure 2). A section is defined in such a way that it is not interrupted by a migration barrier and should be somewhat homogeneous regarding hydro-morphological features and deficits. Thus, at every barrier a new river section begins. In the federal state of Brandenburg the typical length of a river section ranges from 50 to maximum 200 meters. Reproduction habitats as well as connecting river stretches are normally composed of several river sections.

***Figure 2:** Division of planning area into river sections. Example of the Lindower Bäke catchment in Brandenburg*



At the beginning of the planning process it is unknown which river sections will finally be restored to serve as a reproduction habitat or enhanced connecting river stretch containing SST. Hence, for every section the bundle of measures needed to achieve the hydro-morphological quality standard (i) of a reproduction habitat and (ii) of an enhanced connecting river stretch containing SST are planned in sufficient detail. In other words, for each river section up to three basic alternative actions are worked out, depending on its initial condition:

1. The section is upgraded to be (a part of) a reproduction habitat.
2. The section is upgraded to be (a part of) a connecting river stretch with SST.
3. The section remains in its initial condition.

Thereby, the expected costs of restoration measures, their administrative enforceability, possible synergies with other political fields as well as the associated uncertainties are documented quantitatively or qualitatively in the GIS. In Brandenburg all these data have been generated as part of the commissioned water development concepts.[7]

Similarly, measures to make migration barriers passable for fish and other relevant migrating aquatic organisms are planned. For each barrier two basic alternatives (plus variations) exist:

1. The barrier is made passable.
2. The barrier remains.

Again, their expected costs, administrative enforceability and synergies with other political fields are documented in the GIS.

The enforceability of a bundle of measures to upgrade a river section or to make a barrier passable is dependent on many different aspects, e.g. the impact of these measures on the adjacent areas as well as land ownership and the type of land use. In Brandenburg these data are electronically available and enable a rough assessment of the enforceability remotely resulting in a quantitative enforceability index (Klauer and Bathe, 2010). The enforceability information supports the decision making process in the subsequent working steps.

[7] It is possible that for a given river section two or more variations exist to upgrade it to a reproduction habitat or to a river stretch with SST. If there is no clear dominance, such variations should be considered as additional alternatives in the following working steps.

At the end of Step 1, for each river section one bundle of measures that upgrade its hydro-morphological quality to a reproduction habitat and one bundle to upgrade the section to an enhanced connecting river stretch with stepping stones are identified. Analogously, for each barrier a bundle of measures that make it passable for aquatic organisms is known. These bundles of measures are characterised with respect to estimated costs, enforceability scores and further impacts. This may also include a list of river sections and migration barriers where no feasible bundles of measures exist.

Step 2: Setting up successful spatial combinations of measures

According to the stepping stone concept, not all river stretches must be restored to achieve overall good ecological status within the planning area. The second step of the BAS*IN*FORM-M methodology investigates the possibilities of locating reproduction habitats and SST. Based on the information gathered in the first step, all spatial combinations of reproduction habitats and connecting river stretches that fulfil the restrictions of the stepping stone concept will be identified (by a GIS-Tool to be developed). Spatial combinations that fail to meet the restrictions are rejected. In BAS*IN*FORM-M the stepping stone concept is translated into the following restrictions:[8]

1. The minimum length of a *reproduction habitat* is *A* meters.
2. The maximum distance between reproduction habitats where the connecting river stretch *contains SST* is *B* meters.
3. The maximum distance between reproduction habitats where the connecting river stretch *contains **no** SST* is *C* meters.
4. The *overall size of the connected river network* is more than *D* kilometres.

The thresholds *A*, *B* and *C* depend on the type of water body and are taken from Table 2. In case of differing spread effect parameters for different species (e.g. fish and macrozoobenthos) the stricter restriction applies. Parameters *B* and *C* also depend on the length of the reproduction habitats. Parameter *D* mainly depends on the habitat needs of reference fish species and should be determined individually by the competent authority.

The result of Step 2 is a list of all combinations of measures that fulfil the requirements of the stepping stone concept within the planning area. For these combinations, the overall costs and enforceability index are calculated. It is the task of Step 3 to select the best combination out of this list.

Step 3: Choosing the "best" combination of measures

In the last step, a final decision is made in an interactive and participatory process. BAS*IN*FORM-M is designed such that several selection criteria can be taken into account, in particular costs and enforceability of measures, but also further criteria such as positive or negative effects on other political fields, e.g. agriculture, nature conservation, flood risk management, recreation, and tourism etc. Additionally, the different and often conflicting interests of stakeholders can be considered at this stage.

Finding a "good" decision is a complex task of balancing advantages and disadvantages, preferences and concerns. No automatic optimisation procedure is appropriate for this task. However, the problem of complexity can be tackled by a two-step approach:

– First, complexity is reduced by using a simplified set of parameters and,

[8] Note that for a river section to qualify as a reproduction habitat or enhanced connecting river stretch the hydrological quality criteria mentioned in Section 2 apply additionally.

– second, this simplification is counterbalanced by the involvement of expert knowledge and participatory processes.

Following this idea, Step 3 consists of two distinct tasks: (1) Generating a short list of options and (2) making a final decision. The first task is to set up a short list of spatial combinations of measures that are considered to be promising as a "best" choice or to provide some useful benchmark for the final decision (see Table 4). We propose the parallel use of the following algorithms, which automatically generates such benchmarks:

– Identify the combination that meets the spatial restrictions with least costs. This combination is the most cost-effective one in a strict sense of "cost-effectiveness".
– Identify the combination with best overall enforceability.
– Identify the least cost combination with some minimum standard for the enforceability score for each river section and migration barrier (best scoring combination).

Other selection algorithms may also be applied. Instead of choosing only one "best" combination, it is possible, and important for the participatory process, to include two or three "good" combinations in the short list (Table 4).

Table 4: *Short list of combinations of measures (hypothetical values)*

Combination of measures	Costs (Mio €)	Administrative enforceability (1-5)
Least-Cost Combination	4.37	2.4
Best-Enforceable Combination	9.78	1.7
Best-Scoring Combination	5.81	2.0
…	….	….

To support the participatory decision process, the relevant information concerning all combinations of the short list could be presented in two complementary formats (using a GIS):

1. Each combination could be displayed as a map, illustrating the system of water bodies including the boundaries of the river sections, the reproduction habitats, stepping stones as well as the abolished and remaining migration barriers.
2. The combinations could be compared by means of a multi-criteria matrix summarising the relevant information on the performance of each combination. The matrix contains quantitative statements about (1) the present value of total costs and (2) its enforceability index, as well as additional quantitative or qualitative criteria, where applicable, as e.g. qualitative assessments on uncertainties.

Both ways of presenting the relevant information – cartographical display and multi-criteria matrix – are an important input into the participatory decision-making process in the second task of Step 3, arriving at a final decision. In this participatory process, decision makers, local experts and stakeholders analyse, discuss, evaluate and interpret the different combinations identified in the first task. They are also encouraged to create variations of these combinations, for example some "compromise combinations" (see Table 5), or even to come up with some totally new combinations of measures inspired by their practical background.

It would be an advantage of using a GIS-based data bank that the performance of a new combination (compliance with the stepping stone concept, present value of costs, enforceability index etc.) is immediately available. In the participatory decision-making process, additional information not included in the data bank and practical, idiosyncratic knowledge on alternative combinations of measures as well as further evaluation criteria can be taken into consideration. By means of informed comparison between combinations and creative generation of new alternatives well-balanced compromises are likely to be identified in the discussion process.

***Table 5:** Enhanced list of combinations of measures (hypothetical values)*

Combination of measures	**Costs (Mio €)**	**Administrative enforceability (1-5)**	**Side effects, synergies**	**Remarks**
Least-Cost Combination	4.37	2.4	-	-
Best-Enforceable Combination	9.78	1.7	-	-
Best-Scoring Combination	5.81	2.0	-	-
Compromise Combination 1	5.37	2.1	Flood Protection	High potential for repopulation
Compromise Combination 2	5.85	1.9	Nature Protection	-
…	…	…	…	…

On this basis, a final decision can be taken by the competent authority. The BAS*IN*FORM-M concept is open to different ways of final decision-making. For example, a formalised multi-criteria decision support and optimisation tool can be applied for this last process (such as Klauer et al. 2006, Reichert et al. 2007). However, as a multitude of different criteria are important for the final decision and specific contingencies typically play an important role, a non-formalised decision procedure that is able to consider different types of uncertainties (cf. Sigel et al 2010) and leaves room for the decision makers' power of judgement seems more appropriate. The authors are confident that decision makers can do this job faster, cheaper and equally reliable in most cases without a formalised tool if their decision is based on a participatory process and if the reasoning for the final decision is well documented.

4 Discussion and Outlook

In practical water management and planning the isolated restoration of single river reaches without considering functional relationships within the river network is still prevailing (DRL 2008: 18). By applying the stepping stone approach, the BAS*IN*FORM-M concept transcends this limitation while, at the same time, taking further criteria such as cost-effectiveness and enforceability of restoration measures into account. BAS*IN*FORM-M offers a step-wise and systematic approach for the identification and localisation of measures to improve river hydro-morphology which are indispensable to meet the ecological objectives of the WFD. The restoration of watercourses on their entire length is neither affordable nor politically feasible given the current land-use claims. Against this background, BAS*IN*FORM-M offers a decision support process that combines elements of cost-effectiveness analysis, multi-criteria analysis and interactive participatory decision making. It satisfies the WFD's requirement of considering cost-effectiveness without neglecting other important criteria.

The stepping stone concept is not yet comprehensively validated for all river types – respective assessments are currently underway. However, there remains a risk that combinations of restoration measures selected according to the stepping stone approach may fail to achieve good ecological water status in an entire planning area. In our view, such a risk is mitigated by the fact that (i) the water status is continuously monitored, (ii) a new programme of measures will be put forward every six years, and (iii) that a full restoration of river courses is typically neither economically nor politically feasible. If distances between the reproduction habitats prove to be too long or if the hydro-morphological standards turn out to be too lax, the concept can be adapted according to the gained knowledge and additional measures can be taken. The danger of short-term failing of environmental objectives has to be accepted as part of the cost-effectiveness principle. However, long-term failure of the good ecological status should be overcome by periodic monitoring and adaptive management.

Another limit of the BAS*IN*FORM-M concept presented in this paper is the significant information requirement originating from the automated set up of combinations of measures in Step 2: individual measures for improving hydro-morphology have to be planned area-wide, including rough data on costs and effects. This seemed not to be a serious limitation in our study area, the German federal state of Brandenburg, because authorities there planned to commission state-wide set-up of "water development concepts", including data on restoration measures. It may, however, hamper direct application in other areas, where comprehensive planning of restoration measures and respective data are not available. We are, nevertheless, convinced that the stepping stone concept will help to improve the efficiency of measures for improving hydro-morphology, because the basic idea – the consideration of ecological spread effects when spatially allocating hydro-morphological measures – may also be applied in less formalised ways than described in this paper.

Notwithstanding, it is likely that degradation of river morphology remains a serious obstacle for achieving area-wide good ecological status in Europe. Table 2 illustrates that the spread effect of reproduction habitats is at maximum as long as their length, and even smaller for lowland rivers. In other words, in order to achieve good ecological status in 100 % of a river network at least 50 % of the network will have to be upgraded to the quality of a reproduction habitat. In light of the large proportion of currently degraded rivers in Germany and elsewhere it becomes apparent that in practise the discussions on exemptions cannot be separated from the discussion on a cost-effective realisation of the WFD's objective of a good water status.

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